

[0001] A USER EQUIPMENT FOR CODE GROUP SYNCHRONIZATION

[0002] This application claims priority from U.S. Patent Application No. 09/576,363, filed May 22, 2000, which is a non-provisional application of U.S. Provisional Patent Application No. 60/136,664, filed May 28, 1999.

[0003] BACKGROUND

[0004] This invention generally relates to spread spectrum Time Division Duplex (TDD) communication systems using Code Division Multiple Access (CDMA). More particularly, the present invention relates to cell search procedure of User Equipment (UE) within TDD/CDMA communication systems.

[0005] Figure 1 depicts a wireless spread spectrum TDD/CDMA communication system. The system has a plurality of base stations 30_1 to 30_7 . Each base station 30_1 has an associated cell 34_1 to 34_7 and communicates with user equipments (UEs) 32_1 to 32_3 in its cell 34_1 .

[0006] In addition to communicating over different frequency spectrums, TDD/CDMA systems carry multiple communications over the same spectrum. The multiple signals are distinguished by their respective code sequences (codes). Also, to more efficiently use the spectrum, TDD/CDMA systems as illustrated in Figure 2 use repeating frames 38 divided into a number of time slots 36_1 to 36_n , such as sixteen time slots 0 to 15. In such systems, a communication is sent in selected time slots 36_1 to 36_n using selected codes. Accordingly, one frame 38 is capable of carrying multiple communications distinguished by both time slot 36_1 to 36_n and code.

[0007] For a UE 32_1 to communicate with a base station 30_1 , time and code synchronization is required. Figure 3 is a flow chart of the cell search and synchronization process. Initially, the UE 32_1 must determine which base station 30_1 to 30_7 and cell 34_1 to 34_7 to communicate. In a TDD/CDMA system, all the base stations 30_1 to 30_7 are time

synchronized within a base station cluster. For synchronization with UEs 32₁ to 32₇, each base station 30₁ to 30₇ sends a Primary Synchronization Code (PSC) and several Secondary Synchronization Code (SSC) signals in the time slot dedicated for synchronization. The PSC signal has an associated chip code, such as an unmodulated 256 hierarchical code, and is transmitted in the dedicated time slot, step 46. To illustrate, a base station 30₁ may transmit in one or two time slots, such as for a system using time slots 0 to 15 in time slot K or slot K+8, where K is either 0, ..., 7.

[0008] One technique used to generate a PSC signal is to use two 16 hierarchical sequences, such as X1 and X2 in Equations 1 and 2.

$$X1 = [1, 1, -1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, 1, -1] \quad \text{Equation 1}$$

$$X2 = [1, 1, -1, -1, -1, -1, 1, -1, 1, 1, -1, 1, 1, 1, -1, 1] \quad \text{Equation 2}$$

Equation 3 illustrates one approach to generate a 256 hierarchal code, y(i), using X1 and X2.

$$y(i) = X1 (i \bmod 16) \times X2 (i \div 16), \text{ where } i = 0, \dots, 255 \quad \text{Equation 3}$$

Using y(i), the PSC is generated such as by combining y(i) with the first row of length 256 Hadamarad matrix, h₀, to produce C_p(i) as in Equation 4.

$$C_p(i) = y(i) \times h_0(i), \text{ where } i = 0, \dots, 255 \quad \text{Equation 4}$$

Since the first row of the Hadamarad matrix is an all one sequence, Equation 4 reduces to Equation 5.

$$C_p(i) = y(i), \text{ where } i = 0, \dots, 255 \quad \text{Equation 5}$$

The $C_p(i)$ is used to produce a spread spectrum PSC signal suitable for transmission.

[0009] To prevent the base stations' communications from interfering with each other, each base station 30_1 to 30_7 sends its PSC signal with a unique time offset, t_{offset} , from the time slot boundary 40. Differing time offsets are shown for time slot 42 in Figure 4. To illustrate, a first base station 30_1 has a first time offset 44_1 , $t_{\text{offset},1}$ for the PSC signal, and a second base station 30_2 , has a second time offset 44_2 , $t_{\text{offset},2}$.

[0010] To differentiate the different base stations 30_1 to 30_7 and cells 34_1 to 34_7 , each base station 30_1 to 30_7 within the cluster is assigned a different group of codes (code group). One approach for assigning a t_{offset} for a base station using an n^{th} code group 44_n , $t_{\text{offset},n}$ is Equation 6.

$$t_{\text{offset},n} = n \cdot 71T_c \quad \text{Equation 6}$$

T_c is the chip duration and each slot has a duration of 2560 chips. As a result, the offset 42_n for each sequential code group is spaced 71 chips.

[0011] Since initially the UE 32_1 and the base stations 30_1 to 30_7 are not time synchronized, the UE 32_1 searches through every chip in the frame 38 for PSC signals. To accomplish this search, received signals are inputted to a matched filter which is matched to the PSC signal's chip code. The PSC matched filter is used to search through all the chips of a frame to identify the PSC signal of the base station 30_1 having the strongest signal. This process is referred to as step-1 of cell search procedure.

[0012] After the UE 32_1 identifies the PSC signal of the strongest base station 30_1 , the UE 32_1 needs to determine the time slot 36_1 to 36_n in which that PSC and SSC signals are transmitted (referred to as the Physical Synchronization Channel (PSCH) time slot) and the code group used by the identified base station 30_1 . This process is referred to as step-2 of cell search procedure. To indicate the code group assigned to the base station 30_1 and the PSCH time slot index, the base station 30_1 transmits signals having selected secondary

synchronization codes (SSCs), step 48. The UE 32₁ receives these SSC signals, step 50, and identifies the base station's code group and PSCH time slot index based on which SSCs were received, step 52.

[0013] For a TDD system using 32 code groups and two possible PSCH time slots per frame, such as time slots K and K+8, one approach to identify the code group and PSCH time slot index is to send a signal having one of 64 SSCs. Each of the synchronization codes corresponds to one of the 32 code groups and two possible PSCH time slots. This approach adds complexity at the UE 32₁ requiring at least 64 matched filters and extensive processing. To identify the code group and PSCH time slot index, 17,344 real additions and 128 real multiplications are required in each PSCH time slot and 64 real additions are required for the decision.

[0014] An alternative approach for step-2 of cell search procedure uses 17 SSCs. These 17 SSCs are used to index the 32 code groups and two possible PSCH time slots per frame. To implement this approach, at least 17 matched filters are required. To identify the code group and time slot, 1,361 real additions and 34 real multiplications are required for each PSCH time slot. Additionally, 512 real additions are required for the decision.

[0015] It would be desirable to reduce the complexity required by a UE 32₁ to perform cell search procedure.

[0016] SUMMARY

[0017] A user equipment (UE) is capable of receiving and transmitting communication signals in a time division duplex using code division multiple access format. The UE receives a primary code synchronization (PSC) signal, the PSC signal is received in a selected time slot in a PSC channel. Secondary synchronization signals are identified. The secondary synchronization signals are received along with the PSC signal. An assigned code group and the selected time slot is determined based on the identified secondary synchronization signals. The assigned code group is out of a predetermined number N of

possible code groups. Each combination of the N code groups and the selected time slot associated with a unique combination of secondary signals from a set of secondary signals which does not exceed $(\log_2 N) + 1$ in number.

[0018] BRIEF DESCRIPTION OF THE DRAWING(S)

[0019] Figure 1 illustrates a prior art TDD/CDMA system.

[0020] Figure 2 illustrates time slots in repeating frames of a TDD/CDMA system.

[0021] Figure 3 is a flow chart of cell search.

[0022] Figure 4 illustrates time offsets used by differing base stations sending primary synchronization code signals.

[0023] Figure 5 is a diagram of the simplified components of a user equipment and a base station using binary phase shift keying modulation for cell search.

[0024] Figure 6 is a flow chart of secondary synchronization code assignment.

[0025] Figure 7 illustrates the simplified components of a user equipment and a base station using quadrature phase shift keying modulation for cell search.

[0026] Figure 8 illustrates the simplified components of a user equipment and a base station reducing the maximum number of transmitted secondary synchronization codes using quadrature phase shift keying modulation.

[0027] Figures 9 to 17 are graphs depicting the performance of various synchronization systems under varying simulated channel conditions.

[0028] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0029] The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout. Figure 5 shows the simplified circuitry of a base station 30₁ and a UE 32₁ for use in cell search. During step-1 of the cell search, the base station 30₁ generates a PSC signal using a PSC spread spectrum signal generator 66 having the time offset in the time slot 42 associated with the base station

30₁. The PSC signal is combined by a combiner 63 with M SSC signals. The combined signal is modulated by a modulator 62 to carrier frequency. The modulated signal passes through an isolator 60 and is radiated by an antenna 58 or, alternately, an antenna array.

The UE 32₁ receives signals using an antenna 70 or, alternately, an antenna array. The received signals are passed through an isolator 72 where they are demodulated by a demodulator 74 to baseband frequency. During step-1 of the cell search, the PSC matched filter 76 is used by the processor 80 to search through all the chips of a frame 38 to identify the PSC signal of the base station 30₁ having the strongest signal.

One approach for detection of a PSC signal location in a frame is as follows. A selected number of positions in the received signal frame, such as forty, having the highest number of accumulated chip matches (i.e. maximum signal strength), are repeatedly correlated at the same positions in subsequent frames 38. Out of the selected locations, the one having the highest number of cumulative matches (i.e. the maximum signal strength) is identified as the location of the PSC signal.

For step-2 of the cell search procedure, the base station 30₁ generates SSC signals, SSC₁ to SSC_M, using SSC spread spectrum signal generators 68₁ to 68_M. To reduce the complexity at the UE 32₁, a reduced number of SSCs are used. By reducing the SSCs, the number of matched filters required at the UE 32₁ is reduced. Additionally, the reduced SSCs decreases the processing resources required to distinguish the different codes. The reduced SSCs also reduces the probability of incorrect detection of a code group number and PSCH time slot index (see Figures 9-15).

One approach to reduce the SSCs is shown in the flow chart of Figure 6. The number of SSCs used, M, is based on the number of code groups and PSCH time slots used per frame, step 54. The number of SSCs, M, is the log base two of the maximum combination number rounded up to the next higher integer, step 56, as in Equation 7.

$$M = \log_2 (\# \text{ of Code Groups} \times \# \text{ of PSCH Time Slots per frame})$$

Equation 7

The base station 30₁ generates, using SSC signal generators 68₁ to 68_M, the SSC signals associated with the base station's code group and the number of PSCH time slots per frame. The SSC signals are combined with each other as well as the PSC signal by combiner 63. Subsequently, the combined signal is modulated by the modulator 62, passed through the isolator 60 and radiated by the antenna 58. The UE 32₁ receives the transmitted signal, passes it through the isolator 72 and demodulates the received signal using the demodulator 74. Using corresponding SSC₁ to SSC_M matched filters 78₁ to 78_M, the processor 80 determines the binary code that SSCs are modulated. Based on the determined binary code, the base station's code group and PSCH time slot index in the frame is determined. To illustrate for a system using 32 code groups and two possible time slots per frame, such as slots K and K+8, the number of binary bits needed to modulate SSCs, M, is six ($\log_2 64$). In such a system, the six SSCs are modulated with six bits using binary phase shift keying (BPSK) modulation. The six SSCs are chosen among the 256 rows of Hadamarak matrix, H₈. The Hadamarak matrix is generated sequentially, such as by Equations 8 and 9.

$$H_0 = (1)$$

Equation 8

$$H_t = \begin{bmatrix} H_{t-1} & H_{t-1} \\ H_{t-1} & H_{t-1} \end{bmatrix}, t = 1, \dots, 8$$

Equation 9

A particular code, C_{k,n}(i), where n is the code group number associated with a SSC is produced using Equation 10. The six rows of Hadamarak matrix, H₈, are r(k) = [24, 40, 56, 104, 120, 136].

$$C_{k,n}(i) = b_{k,n} \times h_{r(k)}(i) \times y(i), \text{ where } i = 0, 1, \dots, 255 \text{ and } k = 1, \dots, 6$$

Equation 10

The value of b_2 to b_6 are depicted in Table 1.

Code Group (n)	$b_{6,n}$	$b_{5,n}$	$b_{4,n}$	$b_{3,n}$	$b_{2,n}$
1	+1	+1	+1	+1	+1
2	+1	+1	+1	+1	-1
3	+1	+1	+1	-1	+1
...
32	-1	-1	-1	-1	-1

Table 1

The value of $b_{1,n}$ is depicted in Table 2.

PSCH time slot order in the frame	$b_{1,n}$
K, where $K = 0, \dots, 7$	+1
$K + 8$	-1

Table 2

Each code corresponds to one SSC, SSC_1 to SSC_6 . To distinguish the differing base stations' SSC signals from one another, each of the base stations' SSC signals has the same offset as its PSC signal. At the UE 32₁, the step-2 of the cell search procedure (i.e. code group number and PSCH slot order detection) is performed as follows. The received baseband signal is first correlated with C_p as per Equation 4 to obtain phase reference. This correlation is performed by PSC matched filter 76 in Figure 5. The phase reference is obtained by normalizing the correlation value obtained at the output of the PSC matched

filter 76. The received baseband signal is also correlated with C_1, \dots, C_6 as per Equation 10 to obtain binary data that represent the code group of the base station 30_1 and PSCH slot order in the frame. This correlation is performed by SSC matched filters 78_1-78_M in Figure 5. These matched filter outputs are derotated before BPSK demodulation. The derotation is performed by complex multiplication of the complex conjugate of the phase reference. The derotated SSC matched filter outputs are BPSK demodulated. The BPSK demodulation is performed by a hard limiter on the real part of the derotated SSC matched filter outputs. As a result, if the real part of the derotated SSC matched filter output is greater than zero, it is demodulated as +1. Otherwise, it is demodulated as -1. The demodulated binary data represents the code group of the base station 30_1 and the PSCH time slot order in the frame as depicted in Table 1 and Table 2, respectively. To ease detection of the six SSCs, the UE 32_1 accumulates the derotated outputs of the SSC matched filters 78_1-78_M over a number of the PSCH time slots, such as four or eight.

Using six SSCs, for 32 code groups and two possible PSCH time slots, requires 653 real additions and 28 real multiplications at the UE 32_1 to identify the code group/PSCH time slot index. For the decision, no additions or multiplications are required. Accordingly, reducing the number of transmitted SSCs in the PSCH time slot reduces the processing at the UE 32_1 .

Alternately, to reduce the number of SSCs even further quadrature phase shift keying (QPSK) modulation is used. To reduce the SSC number, each SSC signal is sent on either an In-phase (I) or Quadrature (Q) component of the PSCH. One extra bit of data associated with either using the I or Q carrier is used to distinguish the code group/PSCH time slots. As a result, the number of SSCs, M , required by Equation 6 is reduced by one.

For instance, to distinguish 32 code groups and two possible PSCH time slots, five SSCs ($M = 5$) are required. The code groups are divided in half (code groups 1-16 and code groups 17-32). When the SSCs are transmitted on the I carrier, it restricts the code groups to the lower half (code groups 1-16) and when the SSCs are transmitted on the Q carrier, it

restricts the code groups to the upper half (code groups 17-32). The five SSCs distinguish between the remaining sixteen possible code groups and two possible PSCH time slots.

A simplified base station 30₁ and UE 32₁ using QPSK modulation are shown in Figure 7. The base station 30₁ generates the appropriate SSC signals for its code group and PSCH time slot using the SSC spread spectrum signal generators 68₁ to 68_M. Also based on the base station's code group/PSCH time slot index, switches 90₁ to 90_M either switch the outputs of the generators 68₁ to 68_M to an I combiner 86 or a Q combiner 88. The combined I signal which includes the PSC signal is modulated by an I modulator 82 prior to transmission. The combined Q signal is modulated by a Q modulator 84 prior to transmission. One approach to produce the Q carrier for modulating the signal is to delay the I carrier by ninety degrees by a delay device 98. The UE 32₁ demodulates the received signals with both an I demodulator 92 and a Q demodulator 94. Similar to the base station 30₁, the UE 32₁ may produce a Q carrier for demodulation using a delay device 96. Obtaining binary data representing the lower or higher half of the 16 code groups and PSCH time slot index is the same as applying BPSK demodulation on the I and Q components of the received signal respectively. The I matched filters 100₁ to 100_M are used by the processor 80 to determine whether any SSC signals were sent on the I component of the PSCH. A decision variable, I_{dvar} , is obtained such as by using Equation 11.

$$I_{dvar} = |rx_1| + |rx_2| + \dots + |rx_m| \quad \text{Equation 11}$$

$|rx_i|$ is the magnitude of the real component (I component) of the i^{th} SSC matched filter output. Likewise, the Q matched filters 102₁ to 102_M are used by the processor 80 to determine whether any SSC signals were sent on the Q component of the PSCH. A decision variable, Q_{dvar} , is obtained such as by using Equation 12.

$$Q_{dvar} = |ix_1| + |ix_2| + \dots + |ix_M| \quad \text{Equation 12}$$

$|ix_i|$ is the magnitude of the imaginary (Q component) of the i^{th} SSC matched filter outputs. If I_{dvar} is greater than Q_{dvar} , the SSC signals were transmitted on the I component. Otherwise, the SSC signals were transmitted on the Q component.

Another approach using QPSK modulation to reduce the number of SSC signals transmitted is depicted in Figure 8. Instead of transmitting the number of SSCs of Figure 7, the number of SSCs, M , representing the code group number and PSCH time slot index is reduced by one. To regain the one lost bit of information by reducing the SSCs, two sets of M SSCs are used. For instance using 32 code groups and two possible PSCH time slots, one set, SSC_{11} to SSC_{14} , is assigned to the lower code groups, such as code groups 1 to 16, and the second set, SSC_{21} to SSC_{24} , is assigned to the upper code groups, such as code groups 17 to 32. For the lower code group, sending SSC_{11} to SSC_{14} on the I carrier restricts the code groups to 1 to 8. The Q carrier restricts the code groups to 9 to 16. Likewise, for the upper code group, in phase SSC_{21} to SSC_{24} restricts the code groups to 17 to 24 and Q SSC_{21} to SSC_{24} restricts the code groups to 25 to 32. As a result, the maximum number of SSCs transmitted at one time is reduced by one. By reducing the number of SSCs, the interference between SSC signals is reduced. Reduced interference between SSCs allows higher transmission power levels for each SSC signal easing detection at the UE 32₁.

A simplified base station 30₁ and UE 32₁ implementing the reduced SSC approach is shown in Figure 8. At the base station 30₁, two sets of M SSC spread spectrum signal generators 104₁₁ to 104_{2M} generate the SSC signals corresponding to the base station's code group and PSC time slot. The corresponding SSC signals are switched using switches 106₁₁ to 106_{2M} to either an I 82 or Q modulator 84 as appropriate for that base station's code group and PSCH time slot. At the UE 32₁, an I set of matched filters 108₁₁ to 108_{2Q} is used to determine if any of the SSCs were sent on the I carrier. A Q set of matched filters 110₁₁ to 110_{2M} is used to determine if any of the SSCs were sent on the Q carrier. By detecting the transmitted I and Q SSCs, the processor 80 determines the base station's code group and PSCH time slot.

One approach to determining which of 32 code groups and two possible PSCH time slots is used by the base station 32₁ follows. After the processor 80 accumulates data from matched filters 110₁₁ to 110₂₄, the code group set, either SSC₁₁ to SSC₁₄ or SSC₂₁ to SSC₂₄, is determined using Equations 13 and 14.

$$\text{var_set 1} = |r_{x11}| + |i_{x12}| + \dots + |r_{x14}| + |i_{x14}| \quad \text{Equation 13}$$

$$\text{var_set 2} = |r_{x21}| + |i_{x22}| + \dots + |r_{x24}| + |i_{x24}| \quad \text{Equation 14}$$

The values, rx₁₁ to rx₂₄, are the number of accumulated matches for a respective SSC, SSC₁₁ to SSC₂₄, received in the I channel. Similarly, ix₁₁ to ix₂₄ are the number of accumulated matches for the Q channel for SSC₁₁ to SSC₂₄. Equations 13 and 14 require a total of 16 real additions. var_set 1 represents the total accumulations of the first SSC set, SSC₁₁ to SSC₁₄. var_set 2 represents the total accumulations of the second SSC set, SSC₂₁ to SSC₂₄. The processor 80 compares var_set 1 to var_set 2 and the larger of the two variables is presumed to be the SSC set transmitted by the base station 32₁.

To determine whether the SSCs were transmitted on the I or Q channel, Equations 15 and 16 are used.

$$\text{var_I} = |r_{xp1}| + \dots + |r_{xp4}| \quad \text{Equation 15}$$

$$\text{var_Q} = |i_{xp1}| + \dots + |i_{xp4}| \quad \text{Equation 16}$$

If var_set 1 is selected as being larger than var_set 2, the value of p is one. Conversely, if var_set 2 is larger, the value of p is two. var_I is the accumulated values for the selected set

on the I carrier and var_Q is the accumulated values on the Q carrier. The larger of the two variables, var_I and var_Q, is presumed to be the channel that the selected set was transmitted over. By ordering the additions in Equations 13 and 14, the values of var_I and var_Q can be determined simultaneously with var_set 1 and var_set 2. Accordingly, determining whether the I or Q carrier was used requires no additional additions. As a result, using QPSK modulation and two SSC sets requires 803 real additions and 36 real multiplications in each time slot and 16 real additions for the decision.

Figures 9 to 15 are graphs illustrating the performance for distinguishing 32 code groups/two PSCH time slots of systems using 32 SSCs 128, 17 SSCs 124 and 6 SSCs 126. The graphs show the performance for various simulated channel conditions. The simulations accumulated the SSC matches at the UE 32₁ over four or eight PSCH time slots and compared the probability of an incorrect synchronization to the channel's signal to noise ratio (SNR) in decibels.

The Figure 9 simulation uses an additive white gaussian noise (AWGN) channel and accumulation over eight PSCH time slots. The Figure 10 simulation uses a single path Rayleigh fading channel with a six kilohertz (kHz) frequency offset and accumulation over four PSCH time slots. The Figure 11 simulation is the same as the Figure 10 simulation except the accumulation was over eight PSCH time slots. The Figure 12 simulation uses an ITU channel with three multipaths with a UE 32₁ moving at 100 kilometers per hour (km/h) and accumulation over eight PSCH time slots. The Figure 13 simulation uses an ITU channel with three multipaths having six kilohertz (kHz) frequency offset and a UE 32₁ moving at 500 km/h with accumulation over eight PSCH time slots. The Figure 14 simulation uses a single path Rayleigh channel having 10 kHz frequency offset with accumulation over eight PSCH time slots. The Figure 15 simulation uses an ITU channel with three multipaths having 10 kHz frequency offset and the UE 32₁ moving at 500 km/h with accumulation over eight PSCH time slots.

Under the simulated conditions of Figures 14 and 15, 6 SSCs 128 outperforms the other techniques 124, 126. As shown in Figures 9 to 13, 6 SSCs 128 performs favorably in comparison to the other techniques 124, 126.

Figure 16 is a graph of the simulated performance of 6 SSCs 114 using BPSK and the two sets of 4 SSCs 112 using QPSK modulation. The simulation used an eight PSCH time slot accumulation of the matches for each SSC and transmission over an AWGN channel. As shown, two set QPSK modulation 112 outperformed 6 SSC BPSK modulation 114.

Figure 17 illustrates the performance of BPSK and two set QPSK modulation accumulating matches over four and eight PSCH time slots. The SSCs were simulated as being transmitted over a single path Rayleigh channel. Performance for both modulation schemes improves with additional time slot correlations. Two set QPSK modulation for four PSCH time slots 116 and eight PSCH time slots 120 outperforms BPSK modulation for four PSCH time slots 118 and eight PSCH time slots 122, respectively.

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